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Modelling of the Overtopping Flow on the Wave Dragon Wave Energy Coverter

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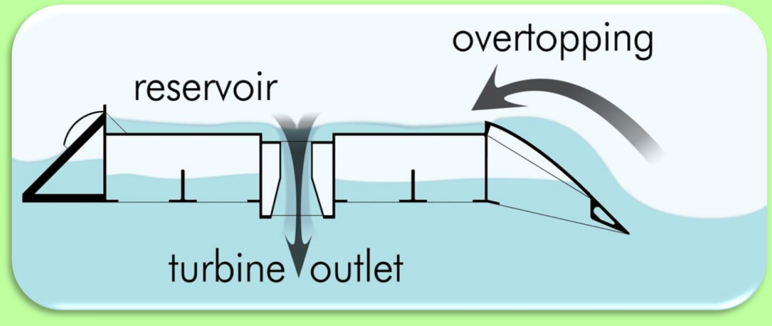

Fig. 1 – Wave Dragon working principle

The Wave Dragon is a floating slack-moored Wave Energy Converter of the overtopping type. Oncoming waves are focused by two arm reflectors towards the ramp of the device, surge-up onto it and overtop into a reservoir placed at a higher level than the Mean Water Level (MWL). The energy production takes place as the water is led back down to the sea through a set of low-head hydro-turbines (Fig. 1).

After more than 10 years of development, Wave Dragon is now facing the the last step before commercialisation: the deployment of a full scale demonstrator.
In this phase it is very important to be able to extend the applicability of the available data to different scales and different locations, in order to have reliable estimates on the power production and performances of the device during the energy conversion process in conditions different from those ones directly tested.
The first and most important step is represented by the modelling of the overtopping flow.
The present study describes the State of the Art of the overtopping modelling of the Wave Dragon and indicates a mehodology for its future development.

I – State of the Art of the Wave Dragon Overtopping model

Hald & Lynggaard (1999) [4]

Strategy – to adapt the coefficients of a known overtopping model, suitable for high crest breakwaters [3], in order to fit experimental results. Use of the wave steepness ($S_{op}=H_s/L$ [-]) to model the observed dependency of the overtopping flow on the wave period T.

Test set-up– 1:51.8 scale model of a North Sea Wave Dragon (Fig. 2).

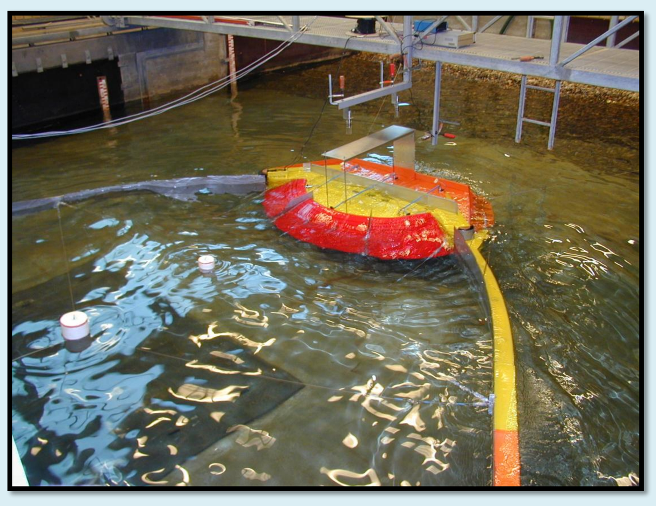

Fig. 2 – The Wave Dragon 1:51.8 scaled model

$$Q_{ND}=\frac{q}{\sqrt{g\cdot H_S^3}}=0.025\cdot\frac{1}{\sqrt{S_{op}/2\pi}}\cdot e^{\left(-40\cdot R_{ND}\cdot\sqrt{S_{op}/2\pi}\right)} \quad (1)$$

Where Q_{ND} is the non-dimensional overtopping discharge per meter crest width and $R_{ND} = R_c/H_s$ is the non-dimensional crest level, being R_c the height of the ramp crest above the MWL.

Kofoed (2001) [5]

Strategy: to experimentally investigate the effect of some parameters influencing the overtopping flow, describing them separately through new coefficients.

Test set-up: 2D, general low crested, draft-limited overtopping device (Fig. 3).

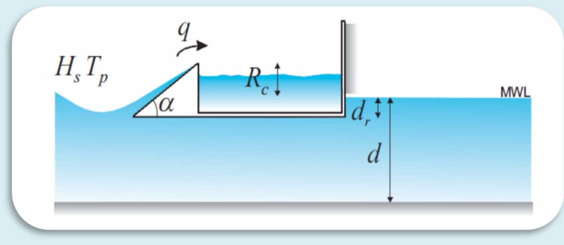

Fig. 3– Sketch of the 2D setup used in the tests

$$Q_{ND}=\lambda_{dr}\cdot\lambda_s\cdot\lambda_\alpha\cdot\lambda_m\cdot 0.2\,e^{-2.6\cdot R_{ND}} \quad (2)$$

- λ_{dr} (-) : effect of the limited draft;
- λ_s (-) : correcting factor due to low crest freeboards (R_{ND} < 0.75);
- λ_α (-) : effect of the slope of the ramp;
- λ_m (-) : effect of the shape of the ramp.

Each factor of interest requires individual investigation, which shall involve a setup as close as possible to the real one

II – Model verification

Fig. 4 – The Wave Dragon 1:4.5 scale prototype in action

➢In the following S_{op} was found not to be a good parameter to use in the model, as it does not scale accordingly with the wave climate from the North sea to NB, where the waves are steeper, leading to underestimate the overtopping.

The overtopping model chosen for the Wave Dragon was therefore (2), also known as Reference Single Level (RSL) formulation. This has successively been validated using the data acquired at the 1:4.5 scale prototype deployed since 2003 in Nissum Bredning (NB), a benign site in northern Denmark (Fig. 4).

The overtopping flow measured at the prototype has been compared to the predictions made by the model, showing a fair agreement, still with some room for improvement.

➢The discrepancies observed (Fig. 5) can be explained in terms of differences between the two set-ups considered at the formulation of the model and its validation: geometrical features, local conditions and scale related parameters (Tab. 1).

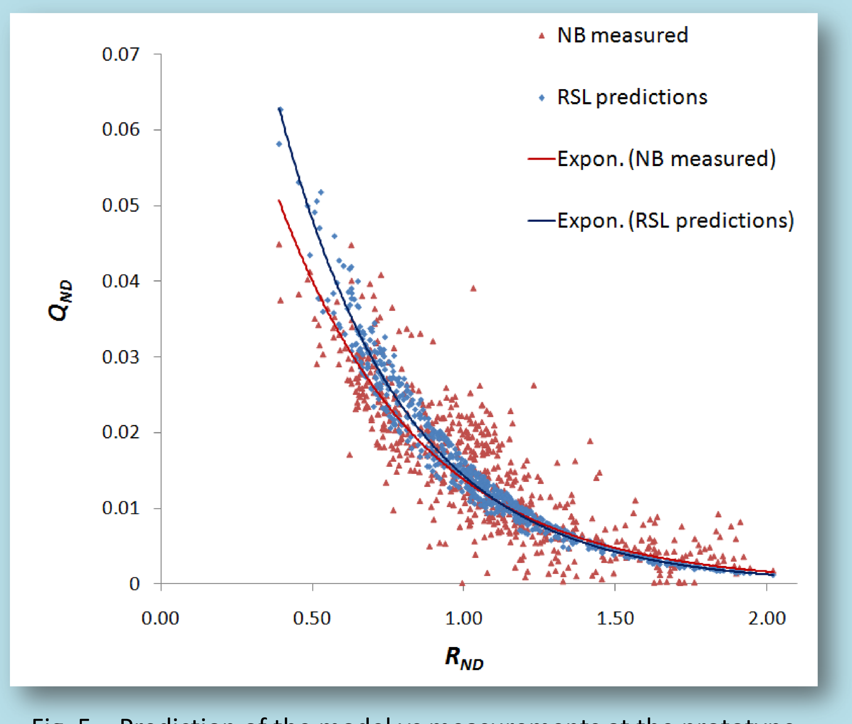

Fig. 5 – Prediction of the model vs measurements at the prototype

IV – Future development

Experimental testing of the overtopping flow on the 1:51.8 scale model.

✓Phase 1 – Establishment of a new reference

Only the fixed platform will be considered. The model's coefficient will be kept as in (2) and the newly formulated parameters will be maintained.
The formulation will be fitted to the experimental results through the formulation of a new parameter, λ_1, describing the effect of the real 3D geometry of the Wave Dragon.
Such model will provide a new reference, specifically suited for the Wave Dragon, for the future investigation of other parameters.

✓Phase 2 – Express the dependency on T

Here the platform will be free floating. The differences observed respect to the results of phase 1 are due to the movements of the platform. As these are dependent on T, they will be described in terms of a parameter λ_2 (T).

✓Phase 3 – Effect of the reflectors' set-up

The reflectors will be added to the model, provided that any of their movements is avoided through a rigid connection. Their presence will affect both the overtopping flow and the stability of the device.
Their effect will be described through a parameter λ_3, depending on characteristics of their set-up such as attachment position and opening angle.

✓Phase 4 – Effect of the rigidity of the reflectors' connection

Different rigidity levels in the reflectors' connection will be tested, reproducing the actual behaviour of the reflectors under different real conditions. The results will be described in terms of a parameter λ_4.

Finally, such an updated model will be validated using the NB prototype data. Differences that might still be observed will be probably due to the spill occurring at low R_{ND} at the prototype. Such undesired occurrence is avoidable in the future through a more accurate control strategy of the device.

III – Set-ups comparison

	Feature	RSL eq. [5]	NB prototype
Geometric features	Scale	± 1:50	1:4.5
	Platform geometry	General, 2D	Definitive for WD, 3D
	Reflectors	Not considered	Definitive geometry, fixed draft, optimal opening
	Stability	Fixed set-up	Free floating, moored set-up
	Control	None	R_c adapted to H_s and control of turbines' on/off strategy (efficiency to improve)
	Spill	Avoided	Occurring at low R_{ND}
Local Conditions	Wave climate	Danish North Sea	NB, higher S_{op} than in the North Sea
	Wave spectrum	JONSWAP, g = 3.3	JONSWAP, g = 6.5
	Reflection	Negligible effect	Open sea
Scale related	Stiffness of reflectors' connection	Reflectors not considered	Low stiffness
	Floatability of the platform	Fixed structure	High damp effect

Tab. 1 – Comparison between the set-ups considered during the formulation and the verification of the overtopping model

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